Electronic Version

Stylesheet Version v1.1.1

Claims

[c1] What is claimed is:

1.A superlens suitable for controlling the size and the phase of an electromagnetic beam, the electromagnetic beam passing through the superlens, the superlens comprising a vertically Graded Refractive Index multi-layer structure, the structure having one or more horizontally curved sidewalls wherein the superlens is used to independently control the vertical and horizontal focusing.

2.The superlens as recited in claim 1 wherein the vertical focusing is controlled by varying the thickness of the structure.

[c2] 3.The superlens as recited in claim 1 wherein the horizontal focusing is controlled by varying at least one of the radii of curvature of the curved sidewall surfaces.

[c3] 4.The superlens as recited in claim 2 wherein the thickness of the structure is varied by etching.

[c4] 5.The superlens as recited in claim 3 wherein the radii of curvature of the curved sidewall surfaces is varied by etching.

[c5] 6.The superlens as recited in claim 2 wherein the electromagnetic beam leaving the superlens is a divergent beam when the thickness of the structure is in the range ((2n-1) x f /4) and (n x f /2), where f is the pitch of the Graded Refractive Index medium and n is a natural number.

[c6] 7.The superlens as recited in claim 2 wherein the electromagnetic beam leaving the superlens is a convergent beam when the thickness of the structure is in the range and (n x f /2) and ((2n+1) x f /4), where f is the pitch of the Graded Refractive Index medium and n is a natural number.

[c7] 8.The superlens as recited in claim 1, wherein the horizontally curved surfaces of sidewalls are one of the spherical, aspherical, cylindrical and toric shapes.

[c8] 9.The superlens as recited in claim 1 wherein the curved surface of the input sidewall and the curved surface of the output sidewall have the same radii of curvature, the input sidewall being the sidewall on which the electromagnetic beam is incident, the output sidewall being the sidewall through which the electromagnetic beam leaves the superlens.

10.The superlens as recited in claim 1 wherein the

curved surface of the input sidewall and the curved surface of the output sidewall have different radii of curvature, the input sidewall being the sidewall on which the electromagnetic beam is incident, the output sidewall being the sidewall through which the electromagnetic beam leaves the superlens.

[c9] 11.The superlens as recited in claim 9 wherein the curved surface of the input sidewall and the curved surface of the output sidewall have a positive radius of curvature.

[c10] 12.The superlens as recited in claim 10 wherein the radius of the curved surface of the input sidewall and the radius of curved surface if the output sidewall have same signs.

[c11] 13.The superlens as recited in claim 10 wherein the radius of the curved surface of the input sidewall and the radius of curved surface if the output sidewall have different signs.

[c12] 14. The superlens as cited in claim 1 wherein the curved surface of the input sidewall and the curved surface of the output sidewall have arbitrary curved shapes.

[c13] 15. The superlens as cited in claim 1 wherein the vertical refractive index profile has arbitrary refractive index

variation.

[c14] 16.The superlens as recited in claim 8 wherein at least one of the input sidewall and the output sidewall has an anti-reflection coating.

[c15] 17.The superlens as recited in claim 14 wherein the anti-reflection coating is designed on the basis of at least one of the central refractive index, the average refractive index and an optimum equivalent index that will lead to maximum electromagnetic wave transmission.

[c16] 18.The superlens as recited in claim 1 wherein the horizontally curved surfaces of sidewalls have a three-dimensional curved surface such that the radius of curvature of the sidewall reduces with the departure from the vertical central region of the Graded Refractive Index distribution.

19.The superlens as recited in claim 1 wherein the Graded Refractive Index distribution of the superlens is a standard distribution.

[c17] 20.The superlens as recited in claim 17 wherein the Graded Refractive Index distribution of the superlens is parabolic.

[c18] 21.The superlens as recited in claim 1 wherein the electromagnetic beam leaving the superlens has at least one

of the circular and elliptical spot sizes.

[c19] 22.The superlens as recited in claim 1 wherein the wavelength of the electromagnetic wave is in the visible range.

[c20] 23.The superlens as recited in claim 20 wherein the vertical and horizontal focusing is used to match the offset for a channel optical waveguide.

24.The superlens as recited in claim 20 wherein the vertical and horizontal focusing is performed to match the vertical and horizontal beam waist of a Gaussian semiconductor laser.

[c21] 25.The superlens as recited in claim 20 wherein the superlens is used for coupling of light between a first waveguide and a second waveguide.

26.The superlens as recited in claim 23 wherein there is an air gap between the first waveguide end face and the superlens input sidewall.

[c22] 27.The superlens as recited in claim 24 wherein there is an anti-reflection coating on the waveguide-to-air interface.

[c23] 28.The superlens as claimed in claim 23 wherein there is an air gap between the superlens output sidewall and the second waveguide face.

[c24] 29.The superlens as recited in claim 26 wherein there is an anti-reflection coating on the air-to-waveguide interface.

[c25] 30.The superlens as recited in claim 23 wherein photolithography is used to have a connection between the superlens and the waveguides.

[c26] 31.The superlens as recited in claim 23 wherein the apparatus is used for coupling of light between a semiconductor waveguide and an optical fiber.

[c27] 32.The superlens as recited in claim 1 wherein the wavelength of the electromagnetic wave is in the Radio Frequency (RF) range or the TeraHertz range.

[c28] 33.The superlens as recited in claim 20 wherein the superlens is used to reduce the spot size of light beams used to record and/or read data from an optical storage device.

34.The superlens as recited in claim 20 wherein the superlens is used for the transformation of a light beam to a small mode size in near-field optics to improve the transmission efficiency.

35.A method of making a superlens, the superlens capable of controlling the size and the phase of an electromagnetic beam, the superlens capable of independently

controlling the vertical and horizontal focus of the electromagnetic beam, the method comprising the steps of:
a.depositing a Graded Refractive Index film on a solid substrate; and
b.forming curved input and output sidewall surfaces by photolithography and etching, the input sidewall being the sidewall on which the electromagnetic beam is incident, the output sidewall being the sidewall through which the electromagnetic beam leaves the superlens.
36.The method as recited in claim 33 wherein the step of forming curved input and output sidewalls comprises the steps of:
a.depositing a metal or polysilicon layer on top of the Graded Refractive Index film;
b.spin-coating a photoresist film on the metal or polysilicon layer;
c.writing a horizontal curved surface pattern on a standard photomask;
d.transferring the horizontal curved surface pattern to the photoresist layer using UV exposure with the help of a standard mask aligner;
e.using dry etching to transfer the horizontal curved surface pattern from the photoresist layer to the metal or polysilicon layer; and
f.dry etching the Graded Refractive Index film to create the desired curved surface structure using the metal or

polysilicon layer pattern as a dry etch mask.

[c29] 37.The method as recited in claim 34 wherein the side-wall profile is controlled by varying the plasma processing parameters during dry etching.

[c30] 38.The method as recited in claim 34 wherein dry etching process is used in combination with wet etching process in order to give a vertical curvature to the input and output sidewalls.

[c31] 39.The method as recited in claim 33 wherein the solid substrate is one of the Si, GaAs, AlN, $LiNbO_3$ and quartz substrates.

[c32] 40.The method as recited in claim 33 wherein the solid substrate is a glass.

[c33] 41.The method as recited in claim 33 wherein the method further comprises the step of directly fabricating the superlens on a Si or a GaAs or an InP substrate together with photonic and electronic integrated circuits as well as fiber positioning grooves.
42.The method as recited in claim 39 wherein the step of directly fabricating the superlens comprises the step of using photolithography to define the connection between the superlens and a waveguide.

[c34] 43.The method as recited in claim 33 wherein the method further comprises the step of fabricating the superlens next to a fiber positioning V or U-groove.

[c35] 44.The method as recited in claim 33 wherein the method further comprises the step of fabricating the superlens on a substrate next to a flip-chip bonding area.

[c36] 45.The method as recited in claim 33 wherein the method further comprises the step of fabricating the superlens between a fiber positioning V-groove and a flip-chip bonding area.

[c37] 46.A method of independently achieving desired horizontal and vertical focusing of an electromagnetic wave, the independent horizontal and vertical focusing being achieved using a superlens, the superlens comprising a vertically Graded Refractive Index multi-layer structure, the structure having one or more horizontally curved sidewalls, the method comprising the steps of:
a.varying the thickness of the vertically Graded Refractive Index multi-layer structure to control the vertical focusing; and
b.varying the radius of curvature of the horizontally curved sidewalls to control the horizontal focusing.
47.An apparatus suitable for controlling the size and the phase of an electromagnetic beam, the apparatus com-

prising:
a.a substrate;
b.a vertically Graded Refractive index film deposited on the substrate; and
c.curved input and output sidewalls, the input sidewall being the sidewall on which the electromagnetic beam is incident on the apparatus, the output sidewall being the sidewall through which the electromagnetic beam leaves the apparatus.
48.The apparatus as recited in claim 45 wherein the curved input and output sidewalls comprises:
a.one of a metal and a polysilicon layer deposited on the vertically Graded Refractive Index film; and
b.a photoresist layer spin-coated on one of the metal and the polysilicon layer.

[c38] 49.The apparatus as recited in claim 45 wherein the substrate is made up at least one of the Si, GaAs, AlN, $LiNbO_3$ and quartz compositions.

[c39] 50.The apparatus as recited in claim 45 wherein the substrate is a glass.

[c40] 51.The apparatus as recited in claim 45 wherein the connection between the apparatus and a waveguide is established using photolithography.

[c41] 52.The apparatus as recited in claim 45 wherein the apparatus is fabricated in an array form for multi-channel light coupling into or out off a multi-port photonic chip.